IR and Near-IR Remote Sensing of the Atmosphere

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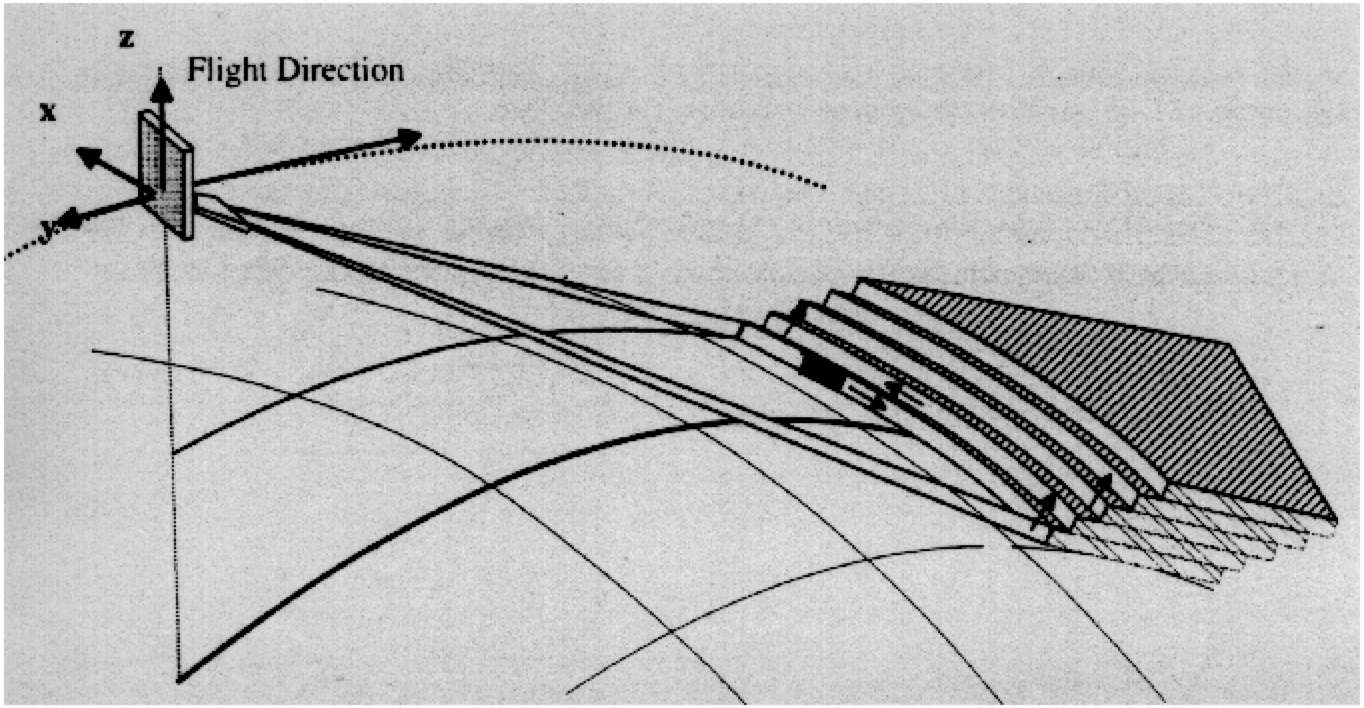
Observing Platforms

- Ground, e.g., NDSC Network, AERI, etc.
- Balloons, e.g., LPMA (Bomem), Denver (Bomem), MkIV (ATMOS), MIPAS-B, etc.
- Rockets
- Aircraft, e.g., NAST-I, ARIES,TES, MIPAS etc.
- Satellites, e.g., TES, IASI, MIPAS, SOFIS, SABER, HIRDLS, ACE, AIRS, CrIS, etc.

Satellite Missions With IR Sensors For Atmospheric Science

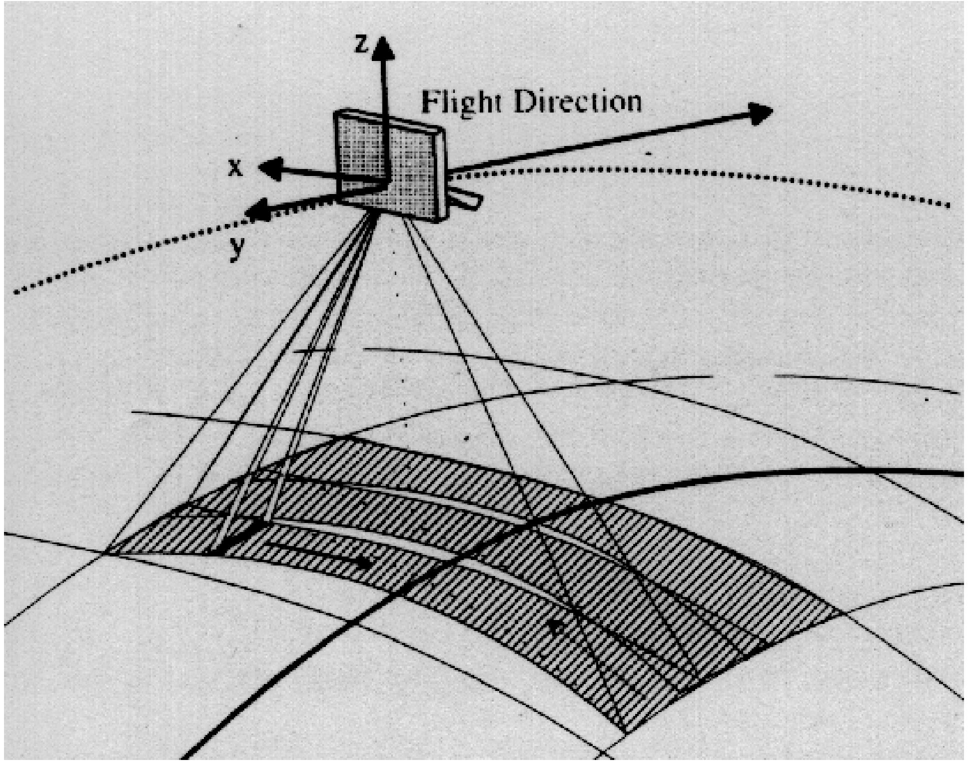
Satellite	Instrument(s)	Life-time
UARS	HALOE, etc.	1991-?
TERRA	MOPITT	2000-2005(?)
AQUA	AIRS	2002-2007(?)
AURA	TES, HIRDLS	2003-2008(?)
TIMED	SABER	2002-2004
METEOR-3M	SAGE-III	2001?
NPOESS	CrIS	2008-?
ENVISAT-1	MIPAS, SCIAMACHY	2002-2007
METOP-1	IASI	2005-2010
ACE (SCISAT-1)	FTS	2002-2004
ADEOS	ILAS, IMG	1996-1997
ADEOS-II	ILAS-II	2002-2006
GCOM-A1	SOFIS, SWIFT	2006-2011

Limb Observations



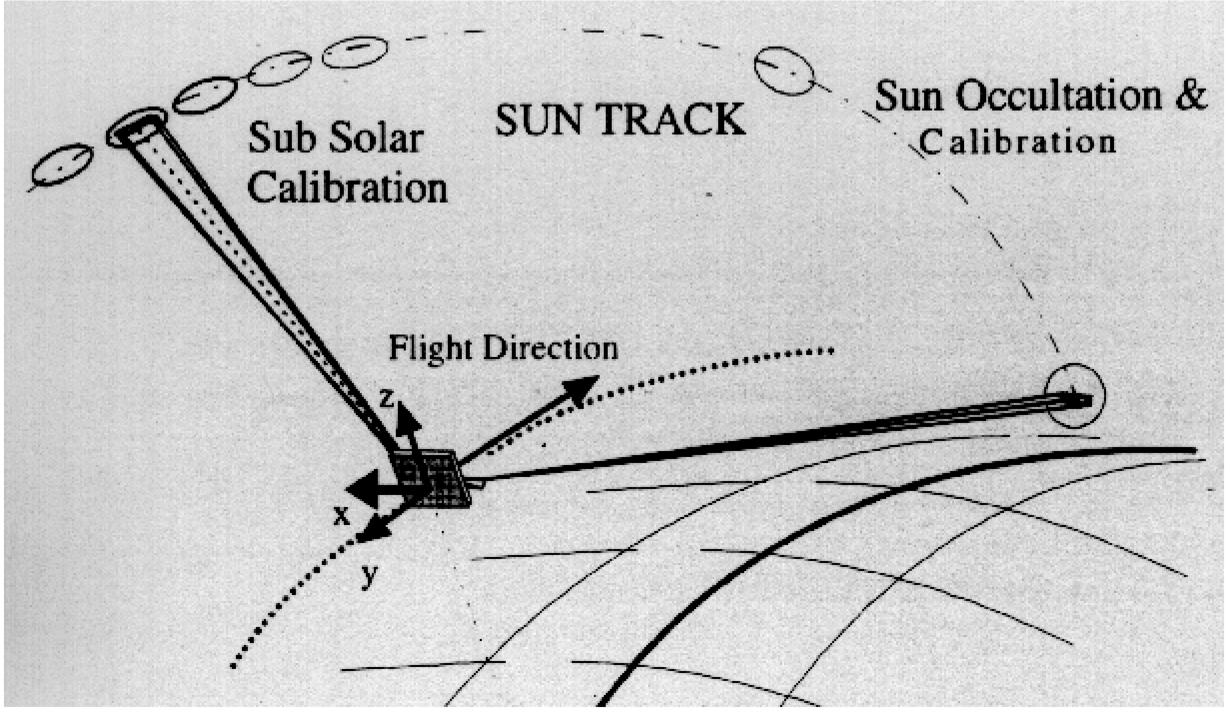
High Resolution: TES, MIPAS
Low Resolution: SABER, HIRDLS, SCIAMACHY

Nadir Observations



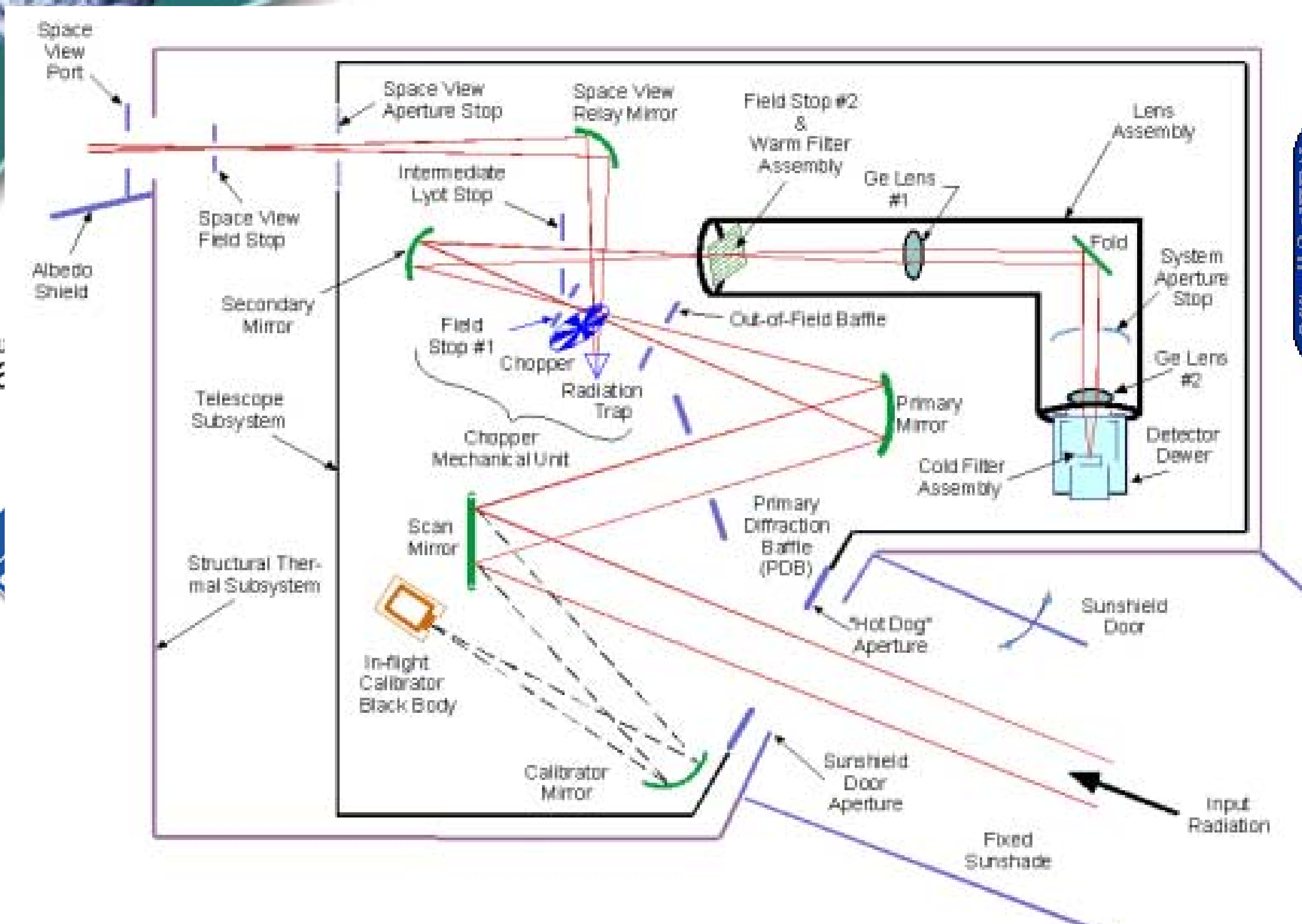
High Resolution: TES
Low Resolution: IASI, AIRS, SCIAMACHY, MOPITT

Occultation Observations



High Resolution: ACE
Low Resolution: SAGE III, ILAS-II, SOFIS, SCIAMACHY

AURA



IR filter radiometer with 21 channels for CO_2 (for T), O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC-11, CFC-12, $ClONO_2$, and aerosols.

HIRDLS on AURA

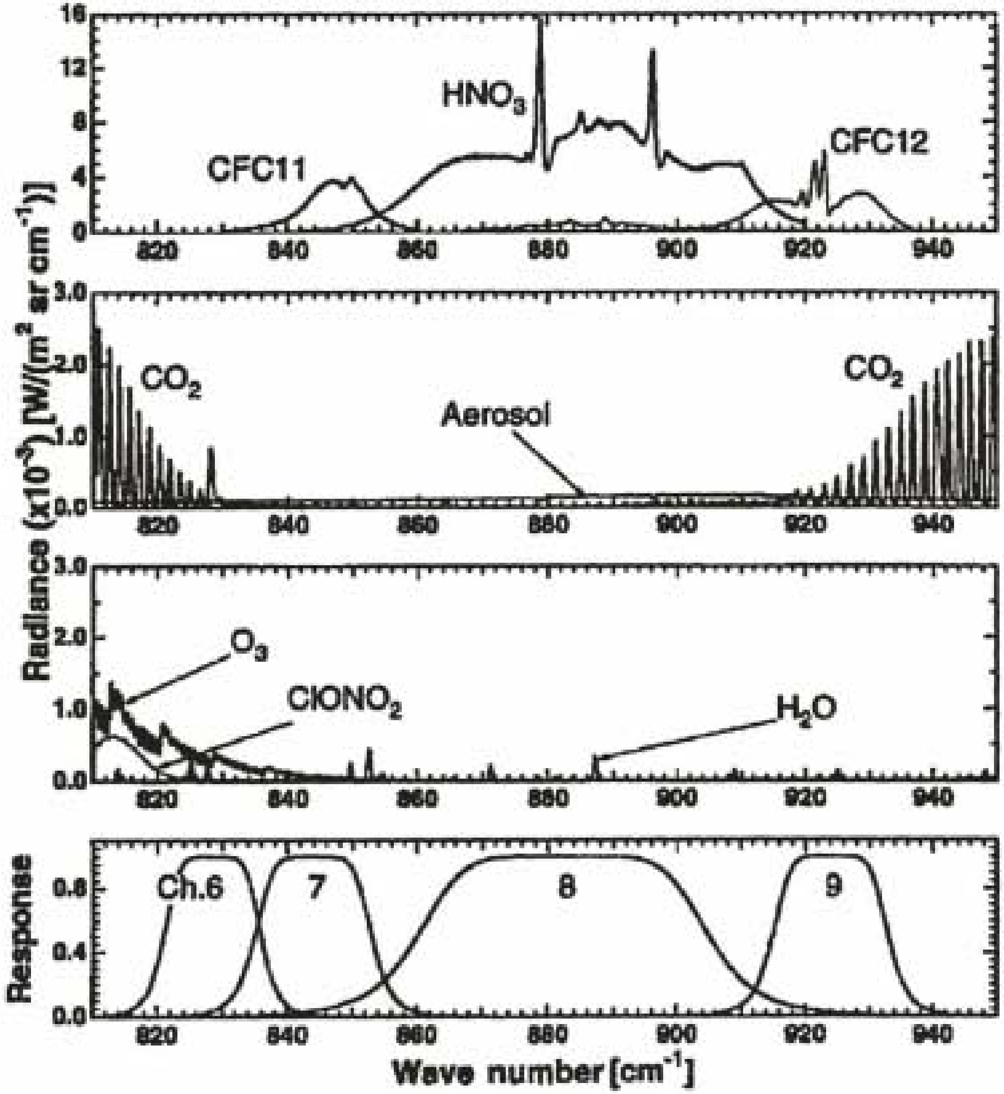
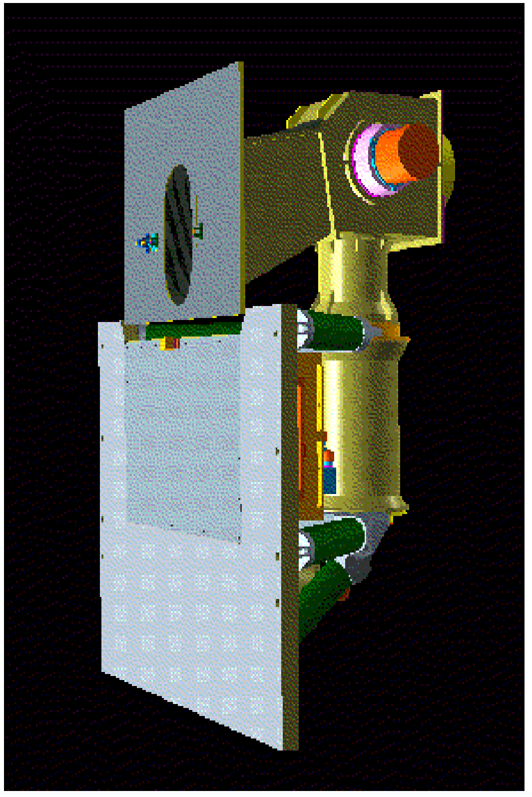


Fig. 4. As for Fig. 1, but for HIRDLS channels 6–9 at a limb-view tangent height of 15 km.

Limb Low Res.- SABER on TIMED

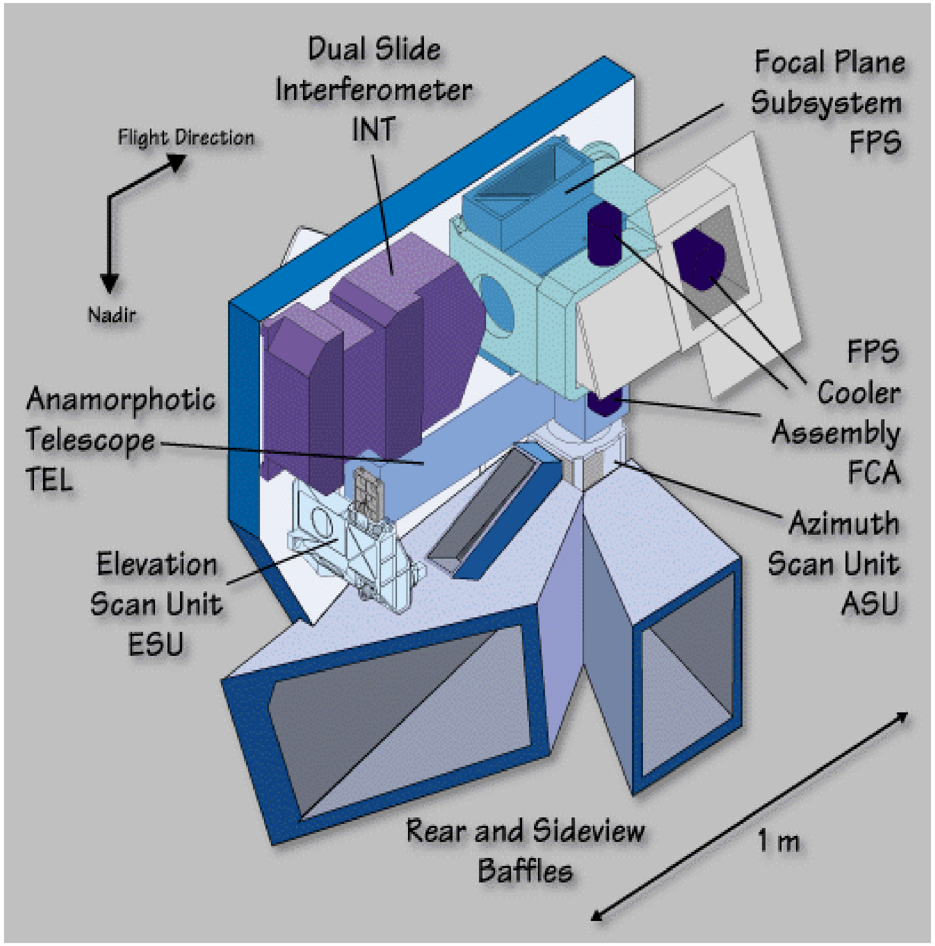
SABER is a limb emission radiometer with 10 infrared channels.



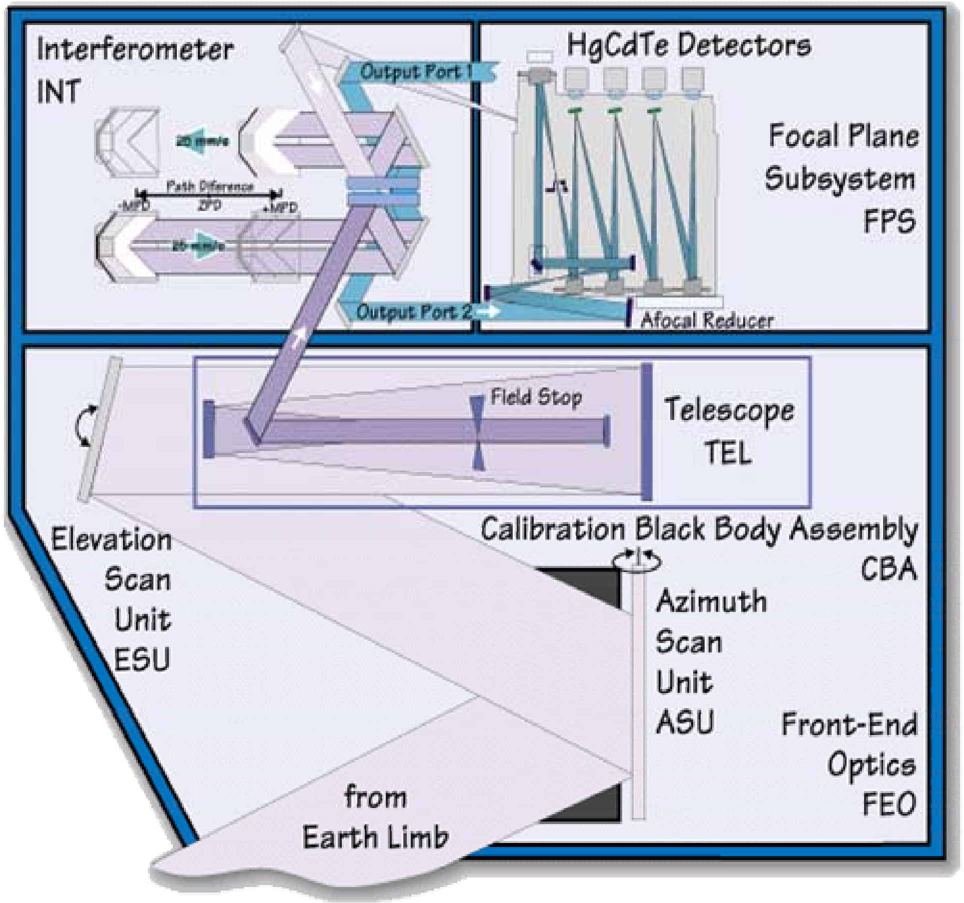
SABER on TIMED

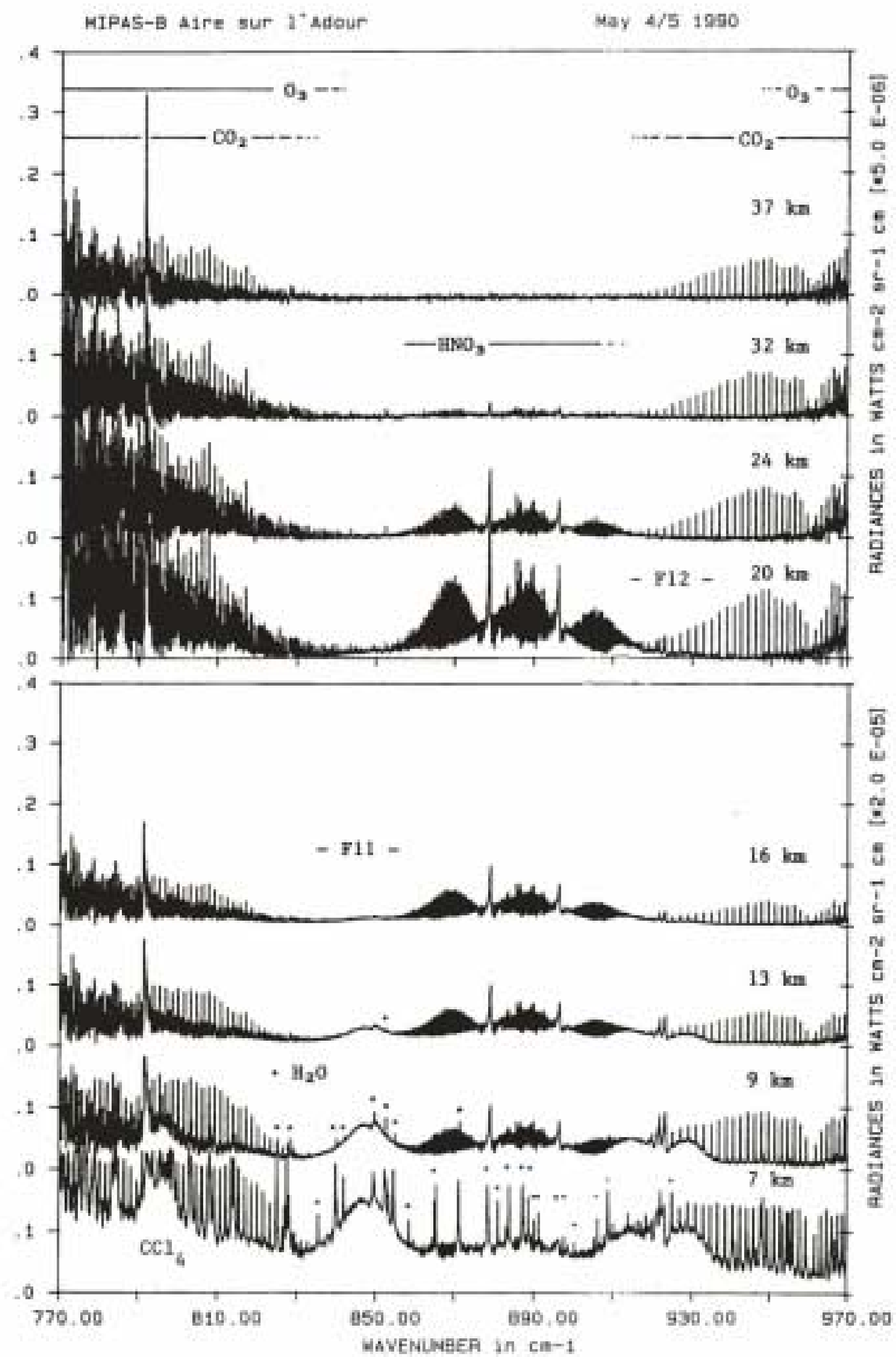
Parameter	Wavelength (μm)	Application	Altitude Range (km)
CO_2	14.9 & 15.2	T, density, IR cooling rates, P(Z), non-LTE	10 - 130
O_3	9.6	O_3 conc., cooling rates, solar heating, chemistry and dynamics studies	15 -100
$O_2(^1\Delta)$	1.27	O_3 conc.(day), inferred [O] at night, energy loss for solar heating efficiency	50 - 105
CO_2	4.3	CO_2 conc.; mesosphere solar heating; tracer	85 -150
OH (υ)	2.0 & 1.6	HO_y chem., chemical heat source, dynamics, inference of [O] and [H], PMC studies	80 - 100
NO	5.3	Thermosphere cooling, NO_x chemistry	90 - 180
H_2O	6.9	HO_x source gas, dynamical tracer	15 - 80

MIPAS on ENVISAT



MIPAS on ENVISAT




MIPAS-B Aire sur l'Adour
May 4/5 1990
O_3
CO_2
37 km
HNO_3
32 km
24 km
F12
20 km
F11
16 km
13 km
+ H_2O
9 km
7 km
CCl_4
RADIANCES in WATTS cm-2 sr-1 cm [*5.0 E-06]
RADIANCES in WATTS cm-2 sr-1 cm [*2.0 E-05]
WAVENUMBER in cm-1
770.00
810.00
850.00
890.00
930.00
970.00

TES on AURA

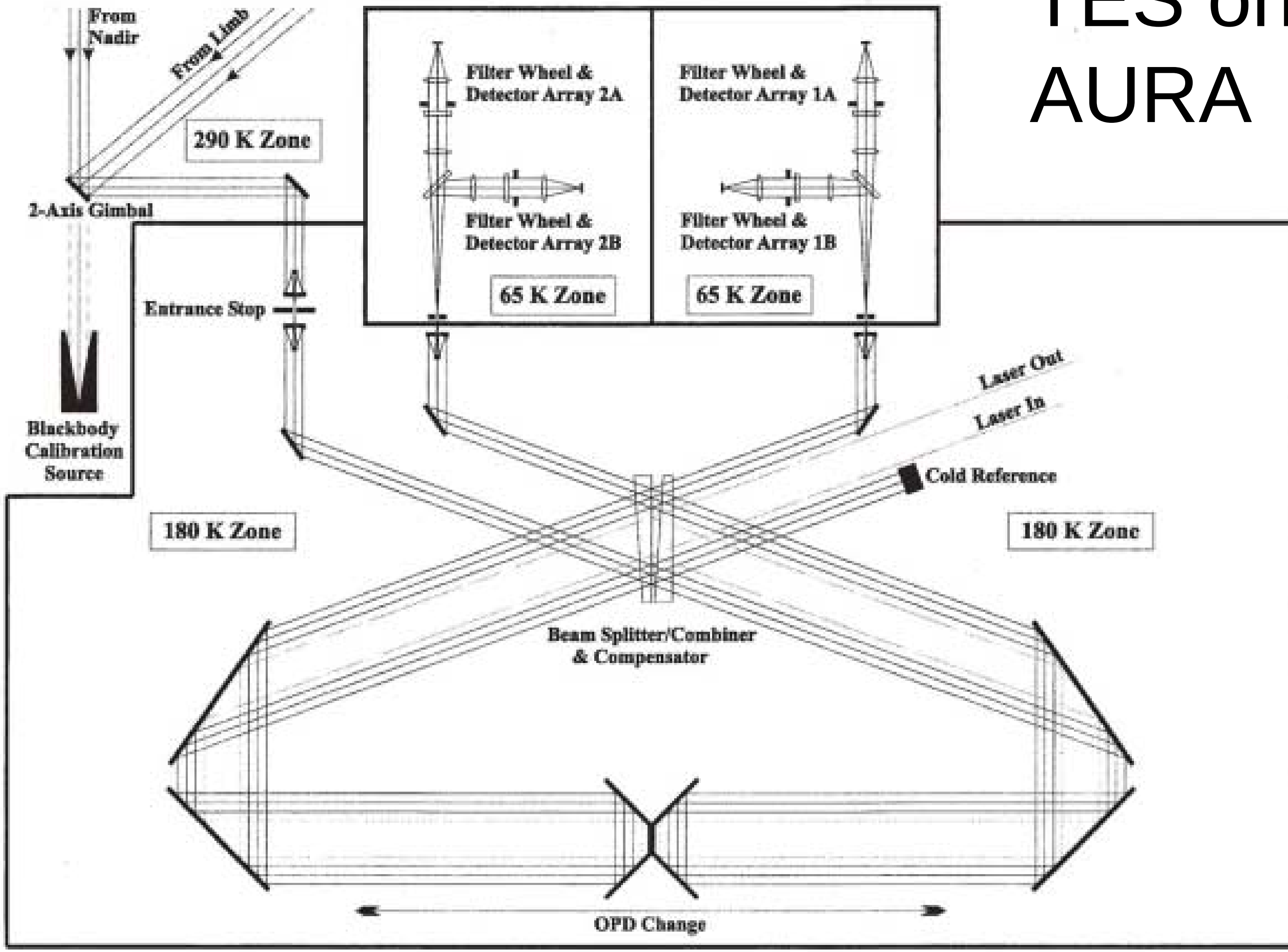


Fig. 4. TES optical schematic (Earth upward in this view). Light enters at the upper left. Note the three different temperature zones and the labeling of the four detector arrays.

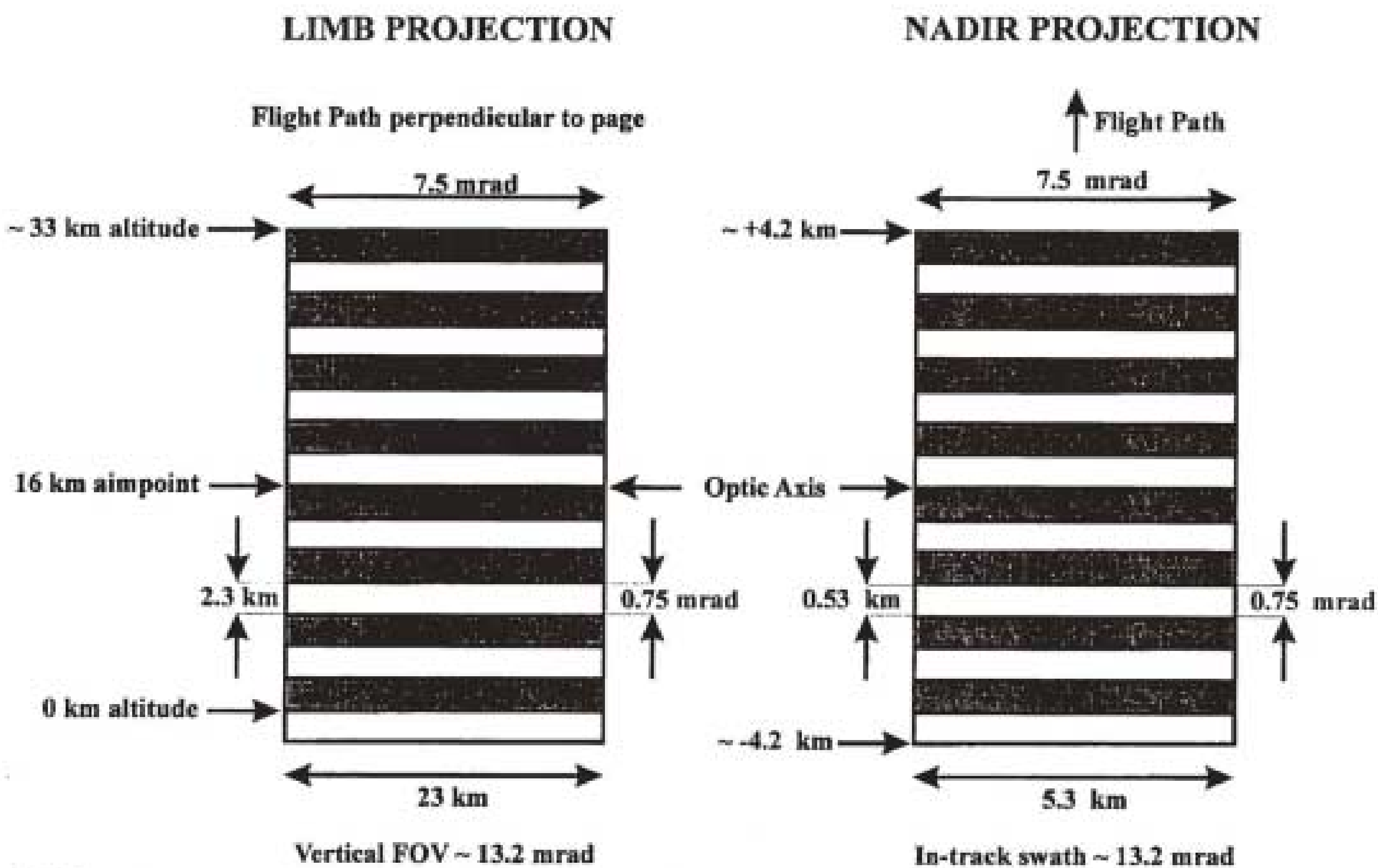


Fig. 3. TES detectors projected to the nadir (705-km range) and to the limb (3100-km range). Although they are shown as discrete elements, the pixels are, in fact, continuous but are defined by an array of contacts underneath. FOV, field of view.

Table 1. TES Standard Products and Required Sensitivity[a]

Product Name	Product Source: Nadir	Product Source: Limb	Required Sensitivity[b]
Level 1A interferograms	Yes	Yes	–
Level 1B spectral radiances	Yes	Yes	–
Atmospheric temperature profile	Yes	Yes	0.5 K
Surface skin temperature	Yes	No	0.5 K
Land surface emissivity[c]	Yes	No	0.01
Ozone (O_3) VMR profile	Yes	Yes	1–20 ppbv
Water vapor (H_2O) VMR profile	Yes	Yes	1–200 ppmv
Carbon monoxide (CO) VMR profile	Yes	Yes	3–6 ppbv
Methane (CH_4) VMR profile	Yes	Yes	14 ppbv
Nitric Oxide (NO) VMR profile	No	Yes	40–80 pptv
Nitrogen dioxide (NO_2) VMR profile	No	Yes	15–25 pptv
Nitric acid (HNO_3) VMR profile	No	Yes	1–10 pptv
Nitrous oxide (N_2O) VMR profile	Yes	Yes	Control[d]

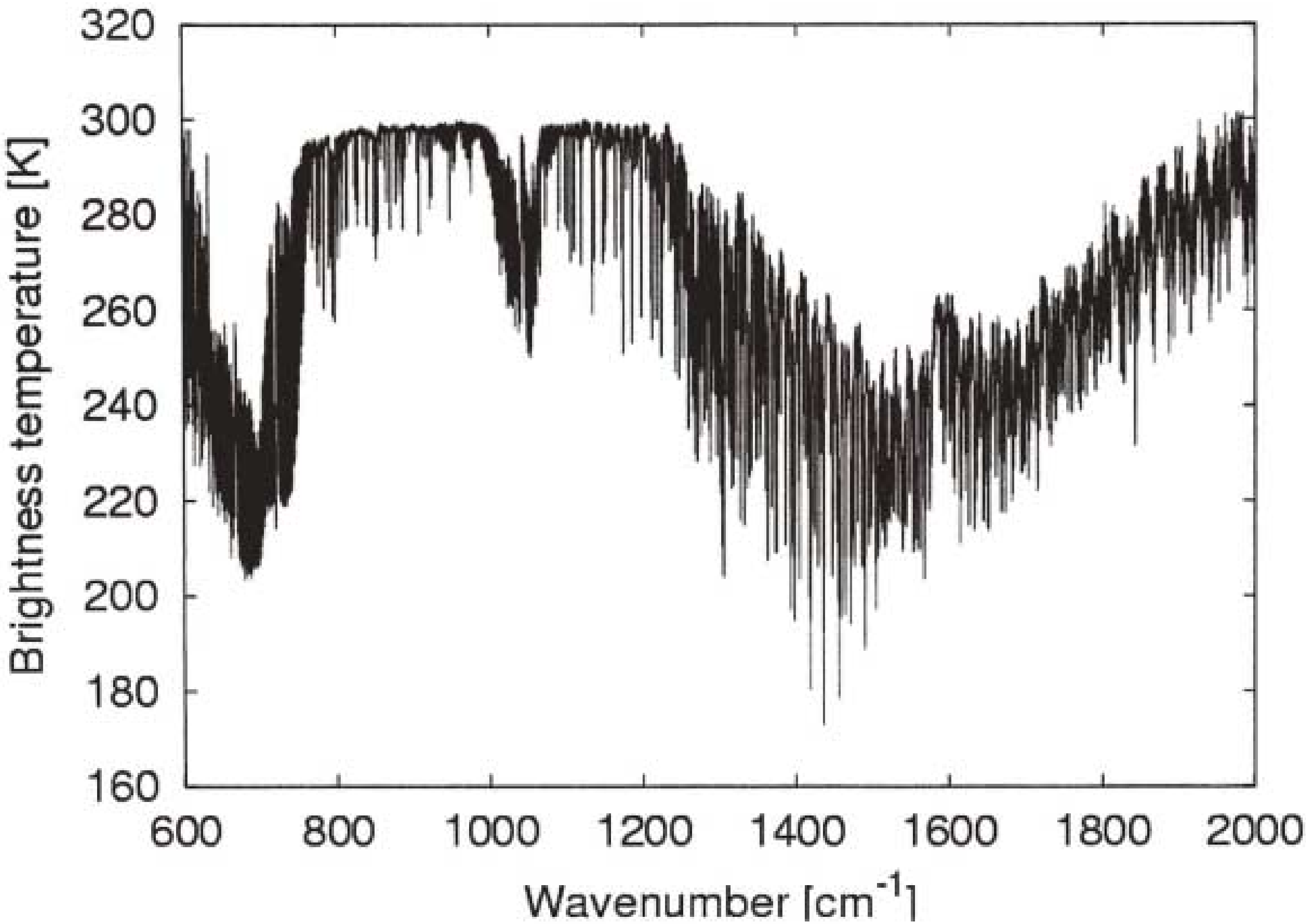
[a]VMR, volume mixing ratio.

[b]Sensitivity range maps to expected concentration range (higher concentration means higher uncertainty): ppbv, parts in 10^9 by volume; ppmv, parts in 10^6 by volume: pptv, parts in 10^3 by volume. Some species (notably NO_x) will require some signal averaging to meet requirements.

[c]Water (and, probably, snow and ice) emissivities are known and are therefore input, not output, parameters.

[d]Tropospheric concentration known.

IMG on ADEOS

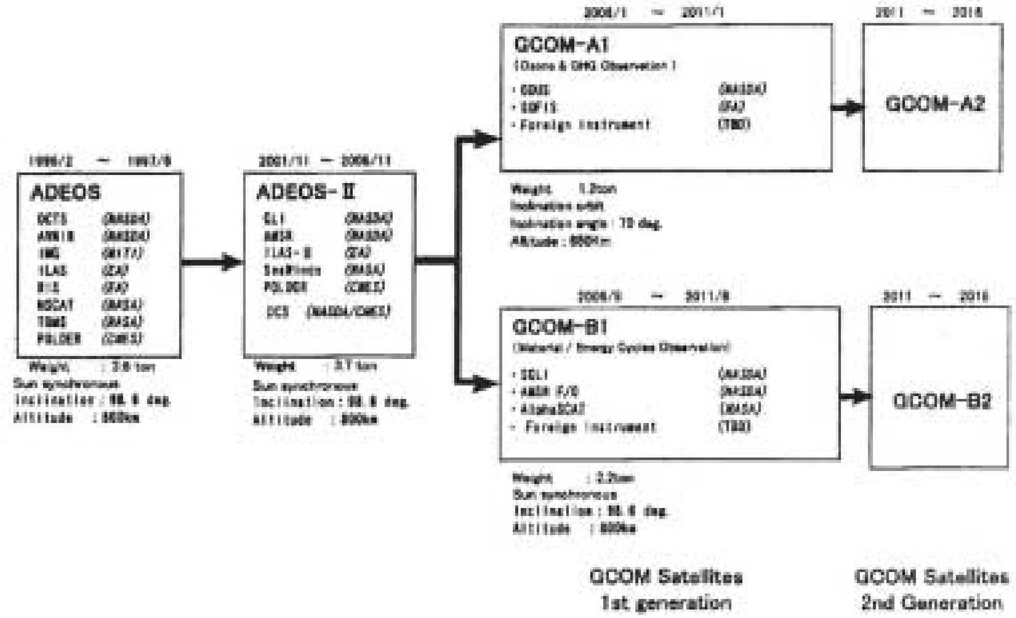


Brightness temperature [K]
320
300
280
260
240
220
200
180
160
600
800
1000
1200
1400
1600
1800
2000
Wavenumber [cm-1]

GCOM (Japan)

Global Change Observation Mission

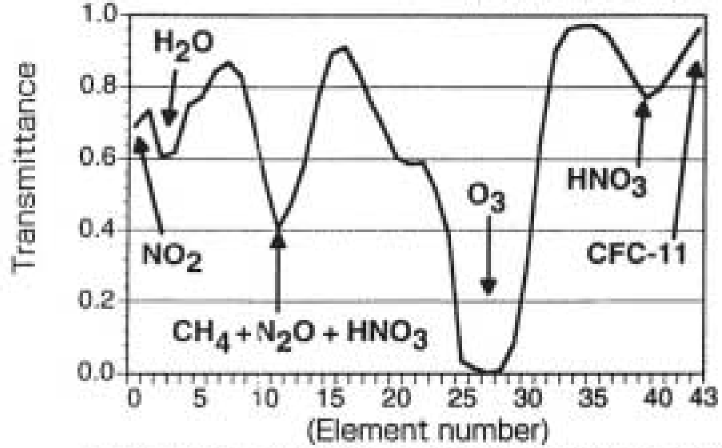
- **GCOM**
  - Global Change Observation Mission.
  - Japan's program to determine trends hidden in climate system.
  - Systematic observation of Land, Ocean, and Atmosphere.
  - At least 15 years, starting from ADEOS-II.
  - Trend detection behind, seasonal, year-to-year, 2-3 years, 11 years, etc. variations.
  - Try to answer to the COP3 "Kyoto Protocol" after 2008-2012.



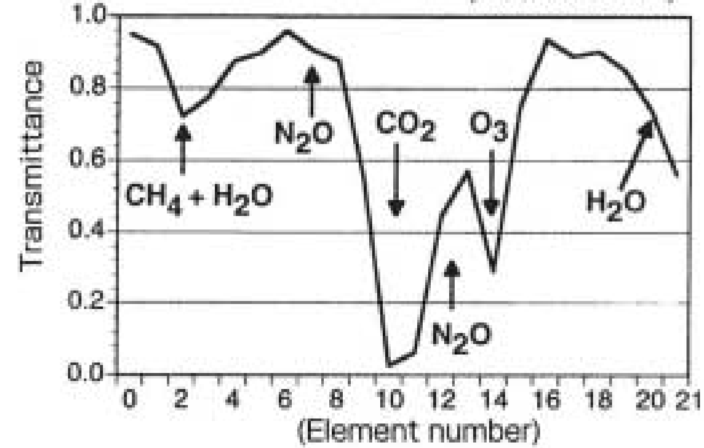
Low Resolution Solar Occultation ILAS-II on ADEOS-II

<table>
<tr><td colspan="2">Spectral Coverage (wavenumber)</td><td>Ch.1: 6.21 - 11.76 μm (1,610 - 850 cm^{-1})
Ch.2: 3.0 - 5.7 μm (3,333 - 1,754 cm^{-1})
Ch.3: 12.78 - 12.85 μm (782 - 778 cm^{-1})
Ch.4: 753 - 784 nm (13,280 - 12,755 cm^{-1})</td></tr>
<tr><td colspan="2">Observation parameters</td><td>O_3, HNO_3, CH_4, H_2O, N_2O, NO_2, CFC-11, CFC-12, $ClONO_2$, aerosol,
temperature, pressure, CO_2 (for pressure measurement)</td></tr>
<tr><td colspan="2">Altitude for measurement</td><td>10 - 60 km
(continuous observation from the cloud tops to 250 km)</td></tr>
<tr><td rowspan="2">Target accuracy</td><td>Altitude resolution</td><td>1 km</td></tr>
<tr><td>Profile</td><td>1 % for ozone, 5 % for trace constituents other than $ClONO_2$, and under study for $ClONO_2$</td></tr>
<tr><td colspan="2">Areas for measurement (latitude range)</td><td>Northern Hemisphere: 57 - 72 degrees
Southern Hemisphere: 65 - 90 degrees</td></tr>
<tr><td colspan="2">Spectrometers</td><td>Ch.1 - Ch.3: Grating spectrograph with array detectors
(Element number Ch.1: 44, Ch.2: 22, Ch.3: 22)
Ch.4: Grating spectrograph (Element number: 1024)</td></tr>
<tr><td colspan="2">Data rate</td><td>453.7 kbps (10 Hz sampling)</td></tr>
<tr><td colspan="2">Weight</td><td>133 kg (max.)</td></tr>
<tr><td colspan="2">Power consumption</td><td>120 W (max.)</td></tr>
</table>

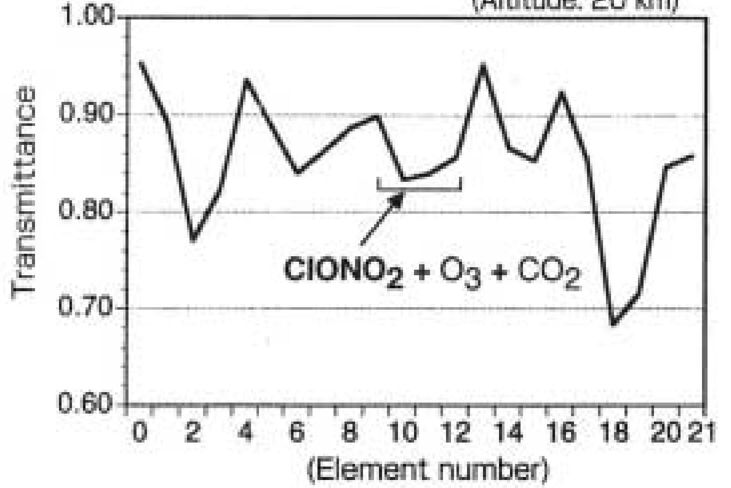
ILAS-II Ch.1: Theoretical atmospheric transmittance (Altitude: 20 km)



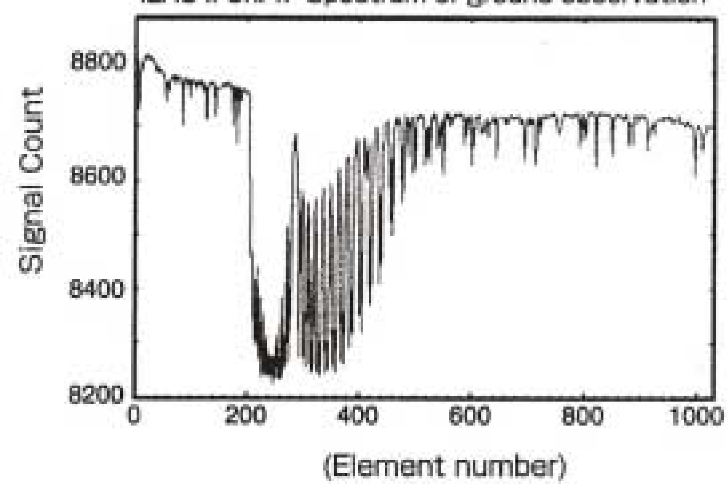
ILAS-II Ch.2: Theoretical atmospheric transmittance (Altitude: 20 km)



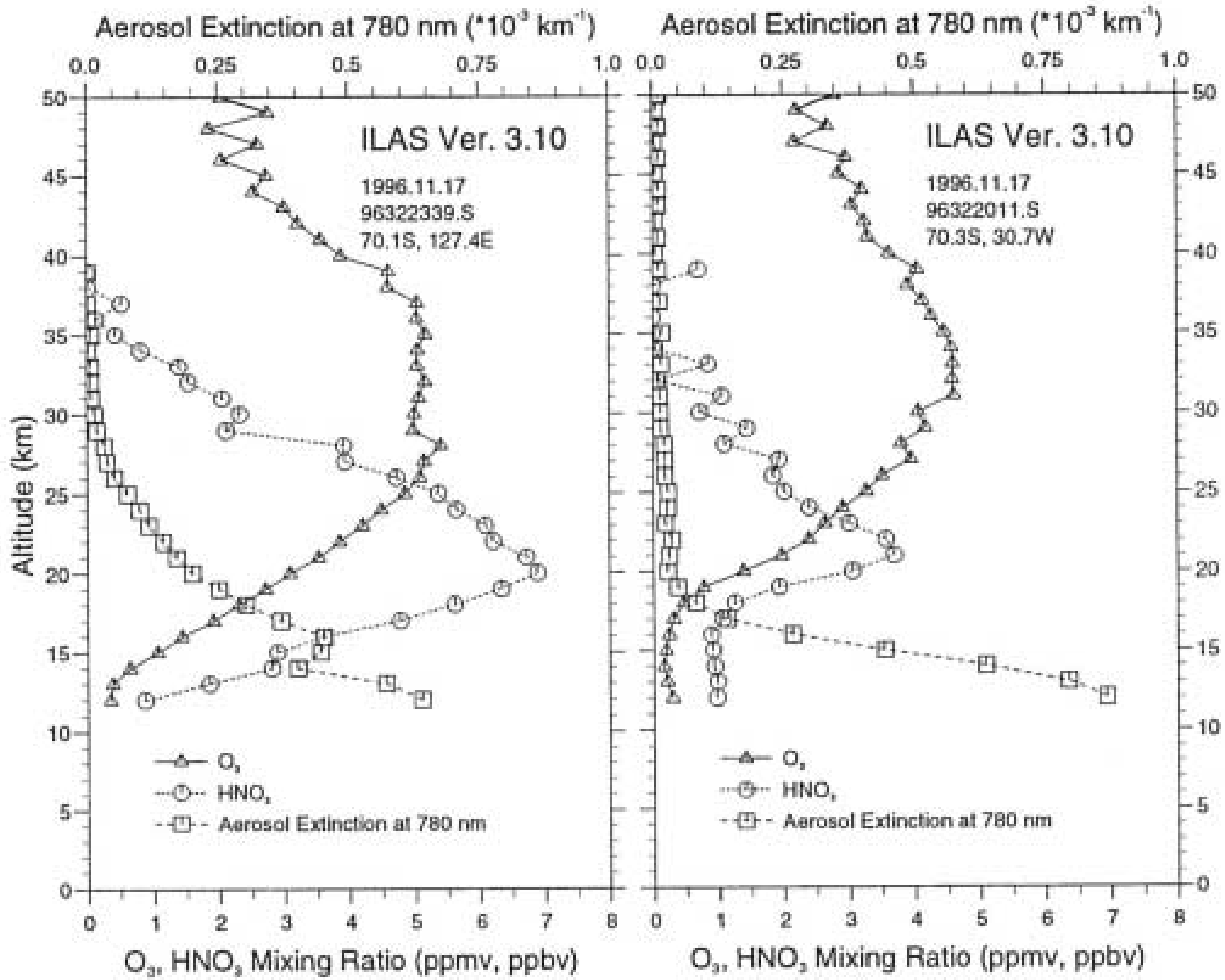
ILAS-II Ch.3: Theoretical atmospheric transmittance (Altitude: 20 km)



ILAS-II Ch.4: Spectrum of ground observation



SASANO ET AL.: ILAS FOR OZONE MEASUREMENTS



ACE Mission Overview

Image © 2000, Thomas Doherty

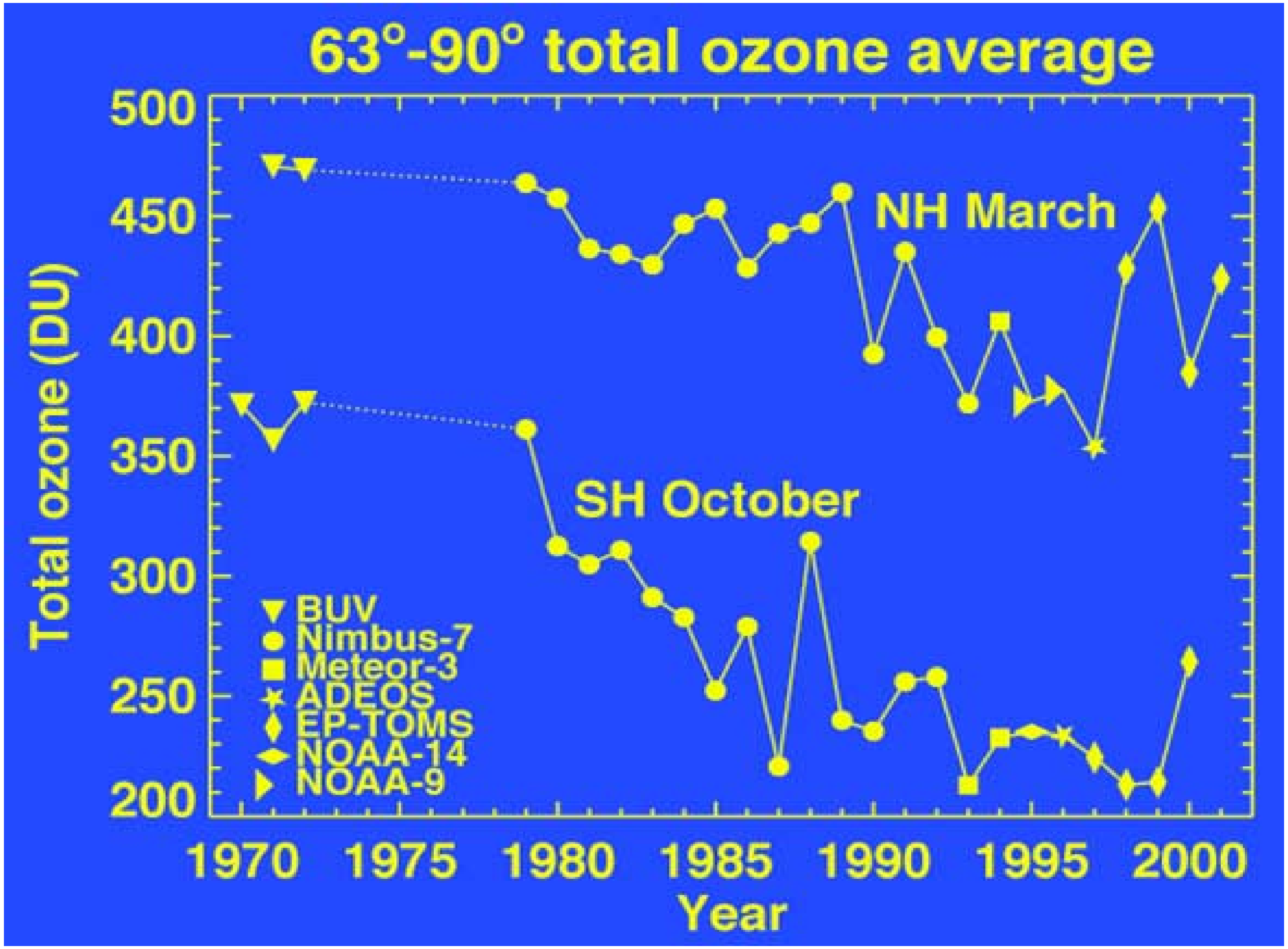
ACE goals

To investigate the chemical and dynamical processes that control the distribution of ozone in the stratosphere and upper troposphere with a particular focus on the Arctic winter stratosphere.

To accomplish this,

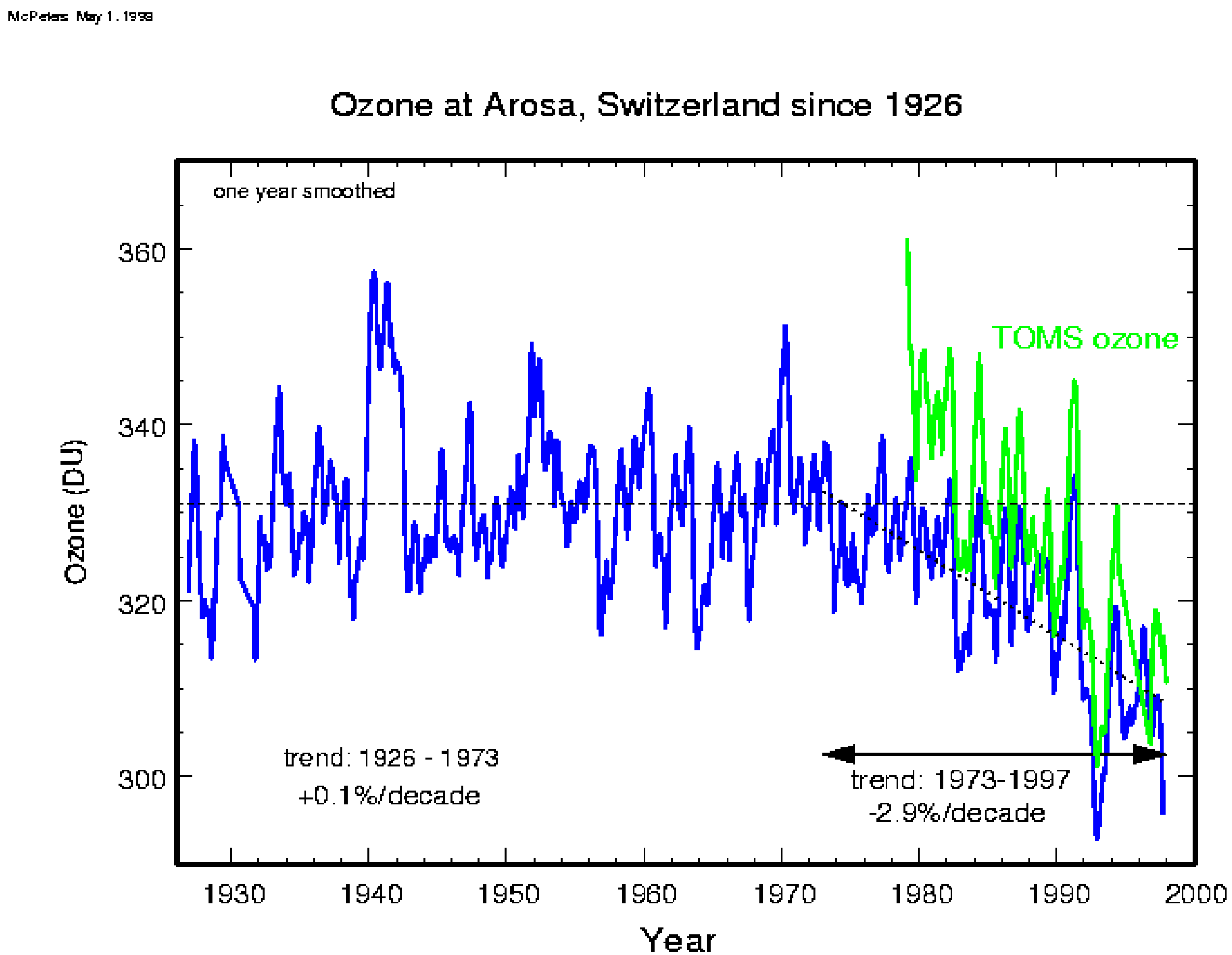
- Temperature and pressure will be measured.
- ACE will measure the concentrations of more than 30 molecules as a function of altitude.
- Aerosols will be measured and quantified.

Polar Ozone Trends (Newman)

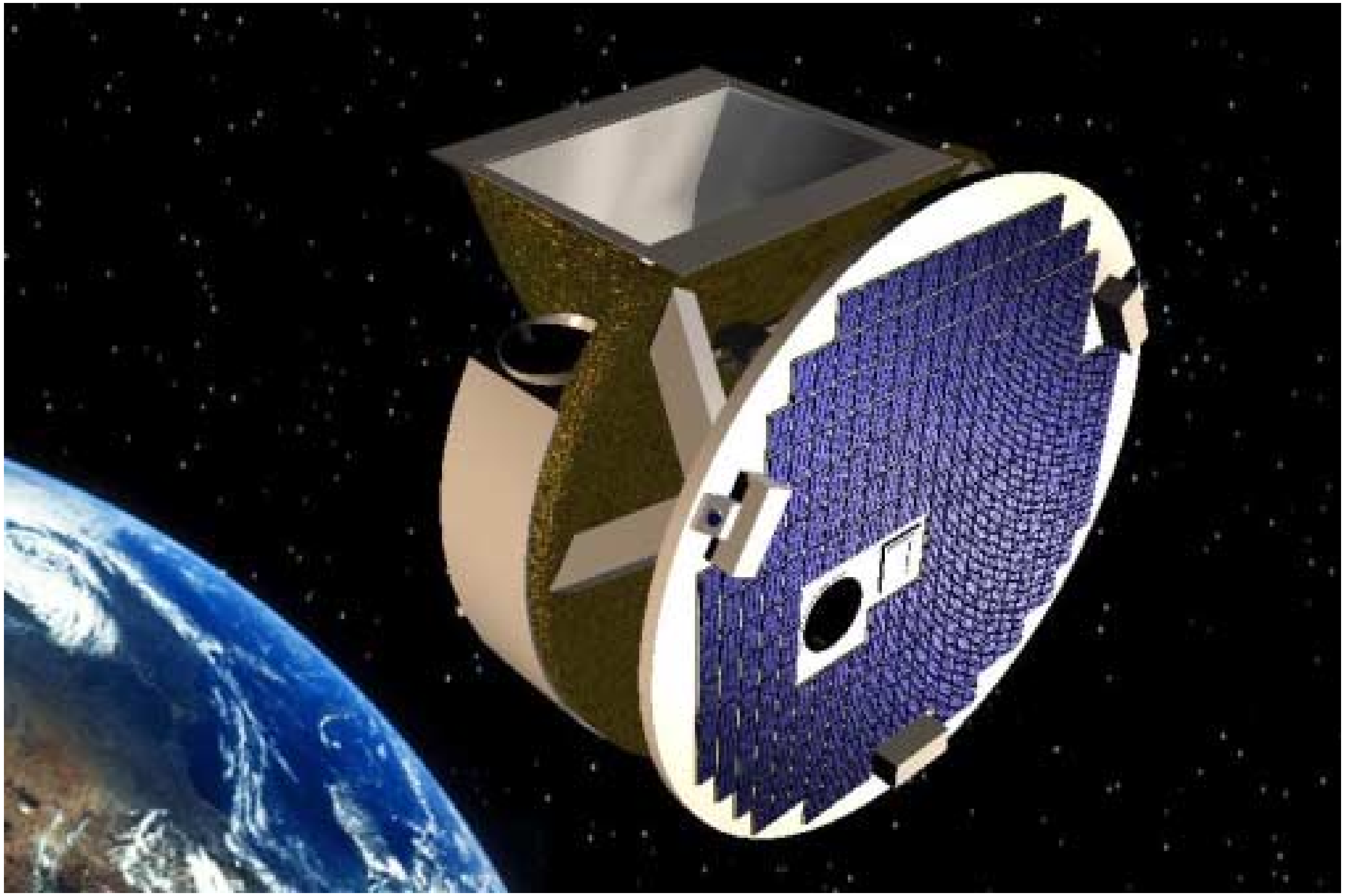


Polar Stratospheric Clouds

Mid-latitude Ozone decline



SCISAT-1

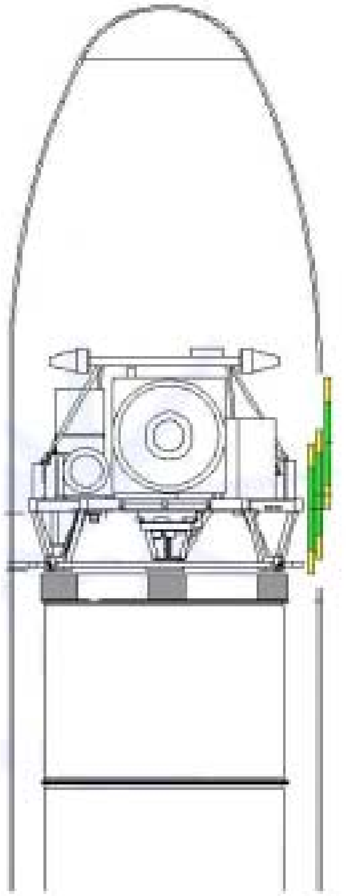


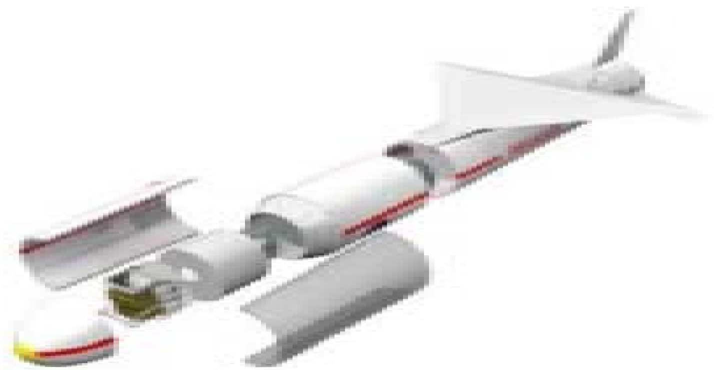
Instruments

- Infrared Fourier Transform Spectrometer operating between 2 and 13 microns with a resolution of 0.02 cm^{-1}
- 2-channel visible/near infrared Imagers, operating at 0.525 and 1.02 microns
- Suntracker keeps the instruments pointed at the sun’s radiometric center.
- UV / Visible spectrometer (MAESTRO) 0.285 to 1.03 microns, resolution ~1 nm
- Startracker

Launch Vehicle

- Pegasus XL Launch Envelope; now baselined as a single spacecraft.
- ACE Mass Allocation:
  - Was 150 kg with co-passenger.
  - Now dedicated: ~270 kg.

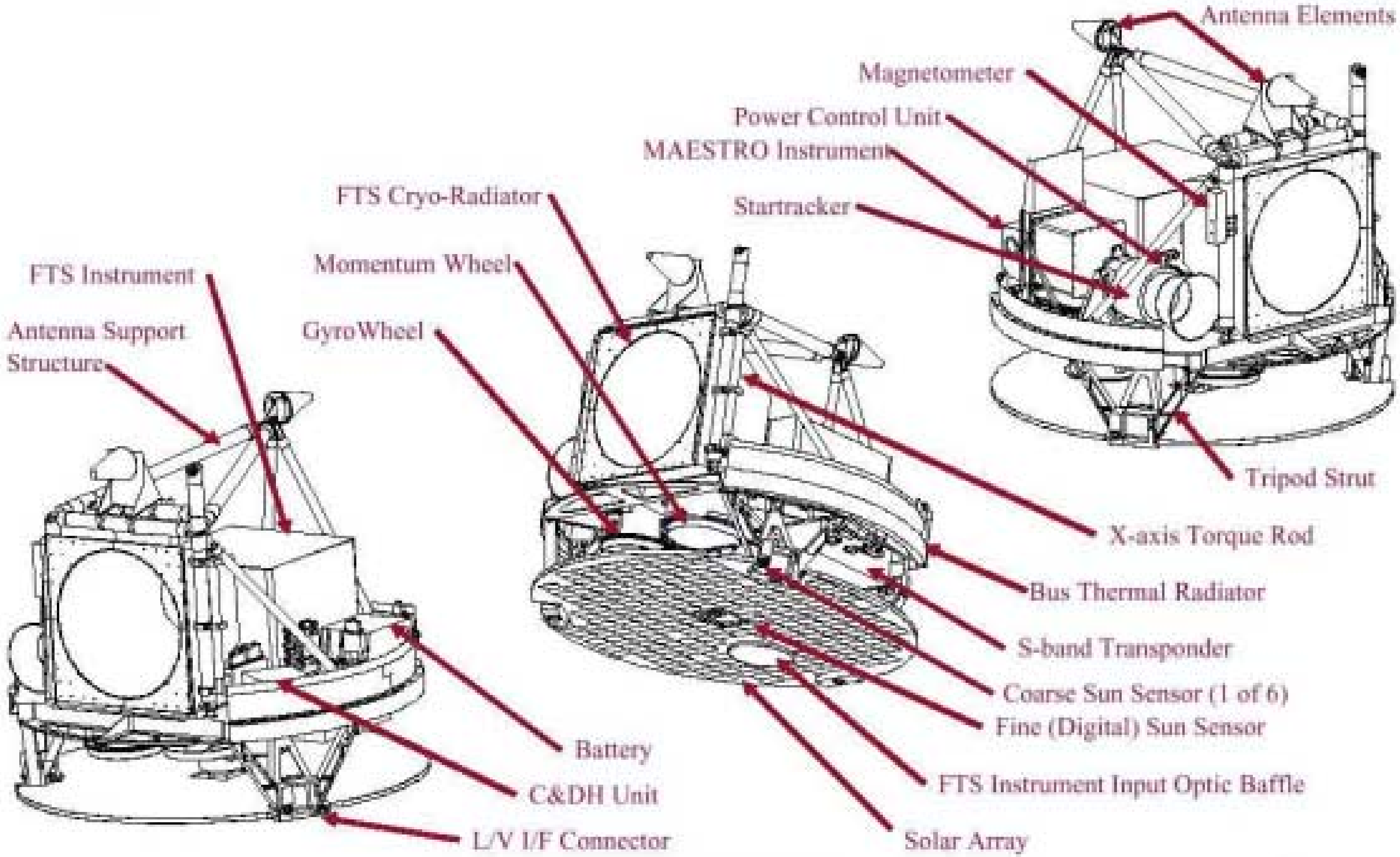




Timeline

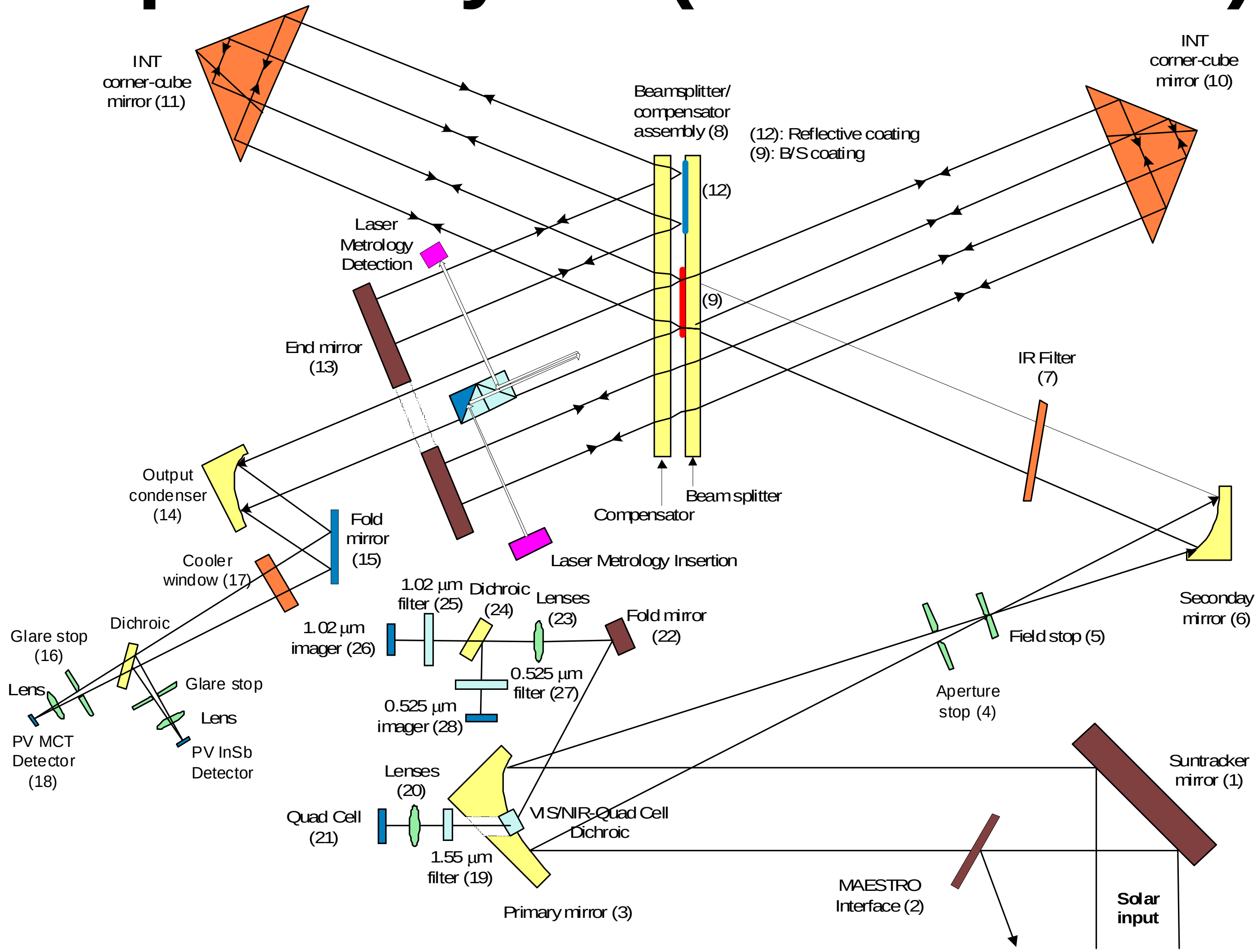
Feb. 2001	FTS and Imager CDR
Mar. 2001	MAESTRO CDR
Jun. 2001	Bus CDR
Mar. 2002	Instrument test
Apr. 2002	S/C integration & test
Oct. 2002	Ready for launch
Dec. 2002	Launch

ACE Payload



Antenna Elements
Magnetometer
Power Control Unit
MAESTRO Instrument
FTS Cryo-Radiator
Startracker
FTS Instrument
Momentum Wheel
Antenna Support
Structure
GyroWheel
Tripod Strut
X-axis Torque Rod
Bus Thermal Radiator
S-band Transponder
Coarse Sun Sensor (1 of 6)
Fine (Digital) Sun Sensor
Battery
C&DH Unit
FTS Instrument Input Optic Baffle
L/V I/F Connector
Solar Array

Optical layout (ABB-Bomem)



FTS Species

MINOR GASES	CO_2, CO, H_2O, O_3, N_2O, CH_4
TRACE GASES	
Nitrogen species	NH_3, NO, NO_2, N_2O_5, HNO_2, HNO_3, HO_2NO_2, HCN
Hydrogen Species	H_2CO, H_2CO_2, HDO, $H_2{}^{17}O$, $H_2{}^{18}O$
Halogens	CCl_3F (F11), CCl_2F_2 (F12), CH_3CCl_3, $CHClF_2$ (F22), CH_3Cl, CCl_4, SF_6, HF, HCl, CF_2O, $ClONO_2$, HOCl
Sulfur oxides	OCS, SO_2
Other species	C_2H_2, C_2H_4, C_2H_6, CH_3D

As well as aerosols and PSC IR spectra

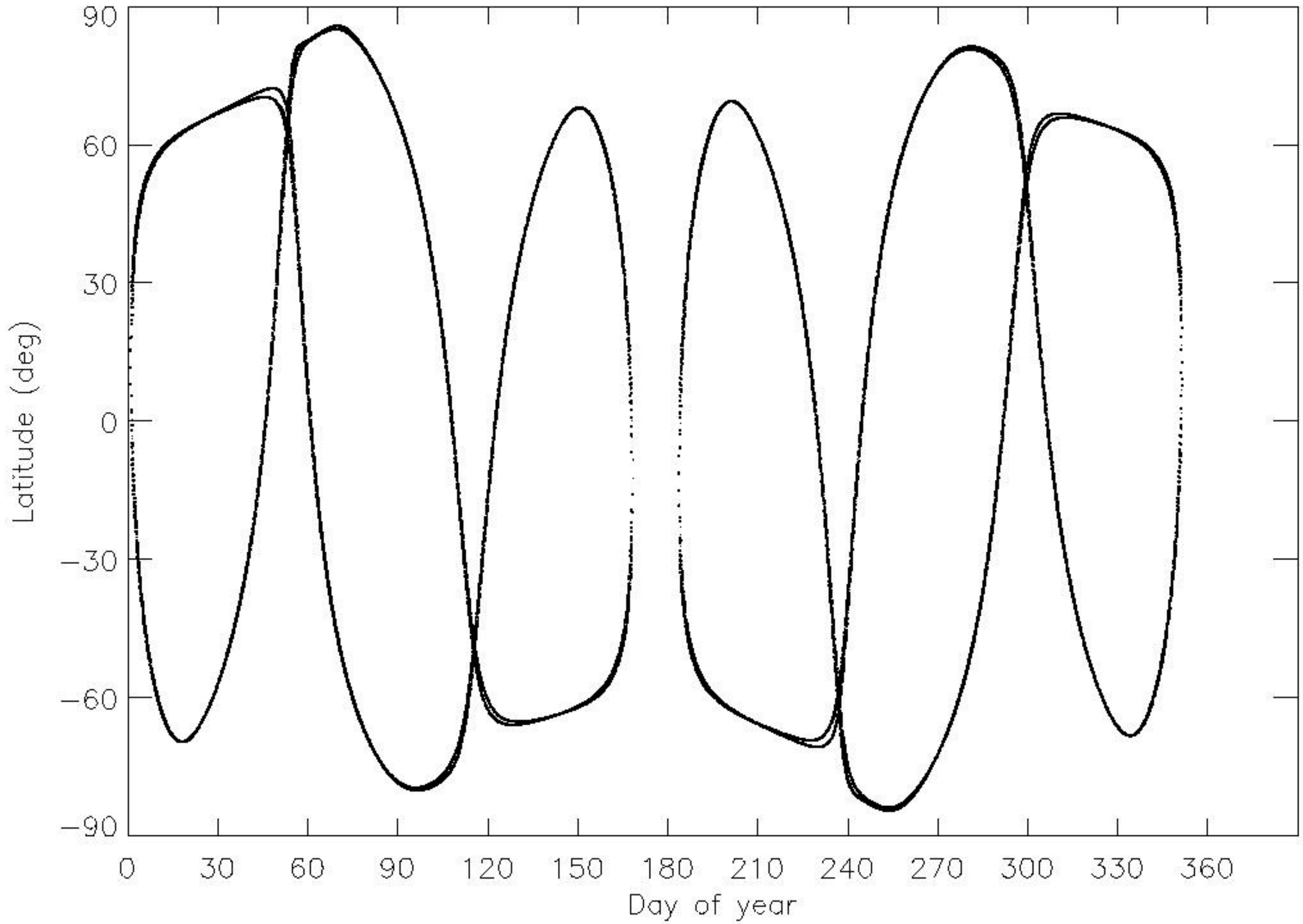
MAESTRO species

- Primary Species: Ozone, NO_2, H_2O, Aerosols and PSCs
- Collateral Products: O_2, $(O_2)_2$
- Secondary Species: SO_2, OClO, BrO, HCHO

ACE Orbit

- A 650 km, 74° inclined circular orbit has been chosen as the optimum for ACE to achieve both global and high latitude coverage.
- Adjustments were made to extend the high latitude measurements during February and March.
- An Earth avoidance maneuver will be required to keep the passive cooler from seeing the Earth's surface.

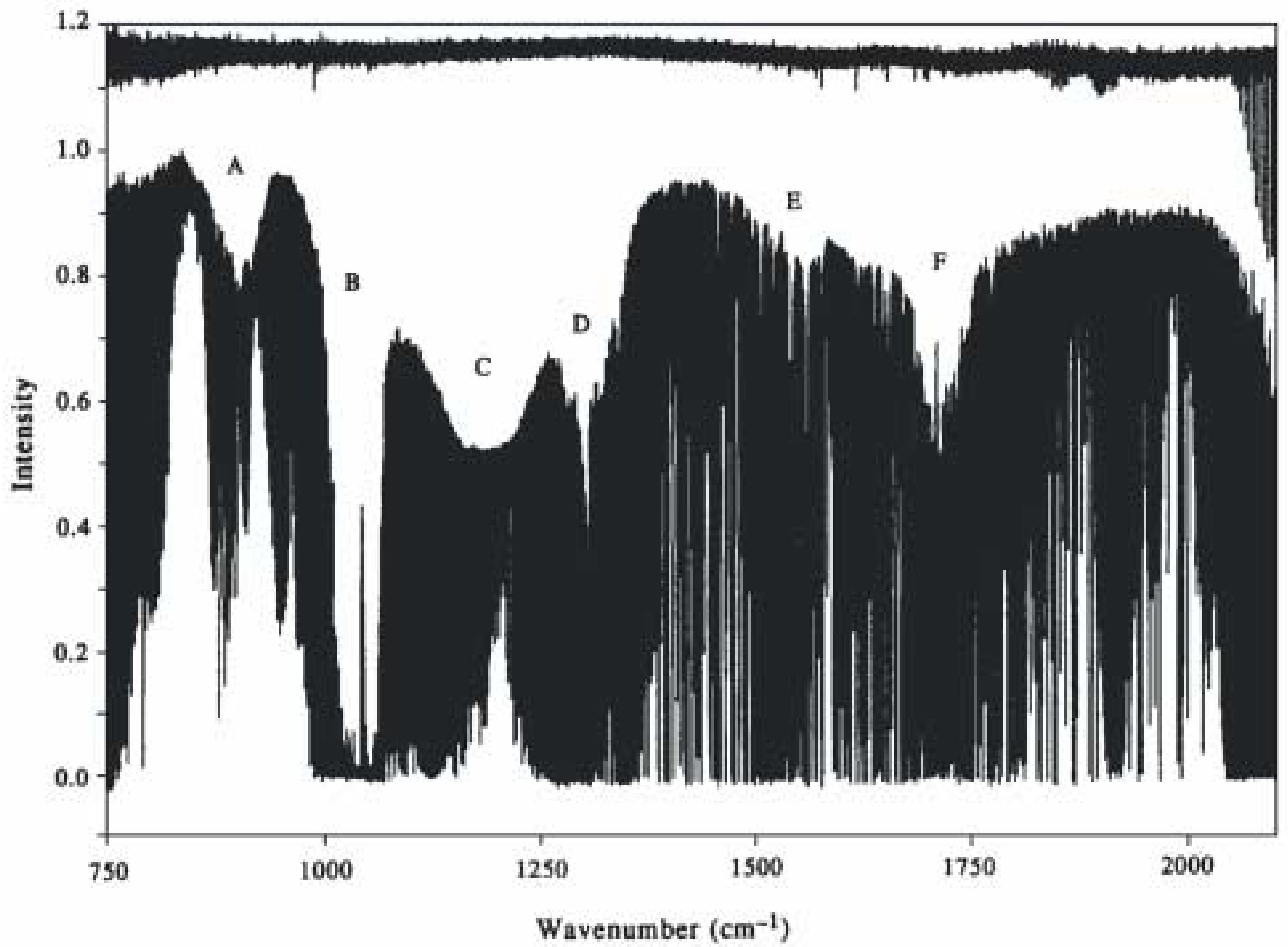
ACE Orbit (RAAN 144°)



FTS Data Analysis

- Processing to occur at the University of Waterloo (along with that for MAESTRO and the Imagers)
- Fitting selected microwindows
- Global Fit approach for retrievals of P/T and of volume mixing ratios
- Operational processing (a new set of data every ~48 minutes)

ATMOS Aerosol Spectrum After Pinatubo



ACE Data Management

- Data is managed in relational SQL databases.
- ACE is using Postgres, an open-source engine.
- Databased quantities include:

Spacecraft data:	ephemeris, housekeeping;
ACE data:	measurement log, spectra;
External data:	input models, linelists, cal/val;
ACE Results:	level 2, level 3;

- This provides standardized access to data, while greatly enhancing our ability to manage it.
- Current size of database is ~40 GB, populated with ATMOS dataset.

ACE Highlights

- Ozone:
  -Vortex O_3 loss
  -Loss details (combine with modeling)
    -Chlorine and Fluorine budgets
    -Gases from reactive Nitrogen family
  -Aerosols and polar stratospheric clouds
  -Mid-latitudes (test case)
- Polar Vortex:
  -Descent (NO and CO)
  -Denitrification and dehydration
  -Chlorine activation (ClO)

ACE Highlights (cont.)

- Post-volcanic sulfate aerosols
- Temperature
- CFC decrease
- Tropospheric chemistry (biomass burning)

- ACE is well suited to the study of aerosols, including composition and size information from the infrared

ACE Participants:

Mission Scientist
- Peter Bernath, University of Waterloo

MAESTRO Principal Investigator
- Tom McElroy, MSC

Instrument Test
- Jim Drummond, University of Toronto

ACE Instrument Support (FTS, MAESTRO, Imagers)
- Pierre Tremblay, Université Laval
- Jim Drummond, University of Toronto
- David Turnbull, University of Western Ontario

Science Operations Center, University of Waterloo
- Chris Boone, ACE Scientist
- Mike Butler, Manager
- Debbie Loney, Admin. Assistant
- Sean McLeod, Computer Support

Additional Canadian University Participants
- Wayne F. J. Evans, Trent University
- Ian Folkins, Dalhousie University
- Ted Llewellyn, University of Saskatchewan
- Bob Lowe, University of Western Ontario
- Ian McDade, York Univeristy
- Jack McConnell, York University
- Diane Michelangeli, York University
- Jim Sloan, University of Waterloo
- Kim Strong, University of Toronto

Instrument Contractor, ABB-Bomem
- Marc-Andre Soucy, Project Manager

Bus Contractor, Bristol Aerospace
- Ian Walkty, Project Manager

MAESTRO Contractor, EMS / MSC
- Andrew Bell, EMS, Project Manager
- Tom McElroy, MSC, Project Manager

Main International Partners

Belgium:
- Reg Colin, Univ. Libre de Bruxelles

France:
- Claude Camy-Peyret, LPMA CNRS

USA:
- Curtis Rinsland, NASA Langley

Canadian Space Agency
- Glen Rumbold, ACE Manager
- Randolph Shelly, Bus
- Victor Wehrle, FTS and Science Team
- Marie Yelle-Whitwan, MAESTRO
- Dennis Ewchuk / Dan Showalter, Ground Segment

DATA NEEDS

High Resolution Data (Molecular Lines)

e.g., H_2O, CO_2, etc.

- Positions (better than 0.001 cm^{-1})
- Intensities (T dependence, as check)
- Shape (T dependence)
  - air broadening parameters
  - pressure shift
  - line mixing, etc.

High Resolution Data (Unresolved Bands)

e.g., SF_6, CFCs, etc.

- High res. (0.01 cm^{-1}) cross-sections as function of T and p

Low Resolution Data

- All of the above.
- Continua including CIA for H_2O, CO_2, O_2, N_2, etc.
- Particle spectra (T, p, size) or complex refractive indices.

DATA NEEDS

<u>High Resolution Data (Molecular Lines)</u>

- Weak lines, e.g., H_2O, CO_2, etc.
- Line intensities (2-3 % accuracy for 180 – 300 K), e.g., HNO_3
- Collisional line widths (180 – 300 K)
- Pressure shifts
- Line mixing (Q-branches of molecules other than CO_2 and CH_4)
- Hot bands (for non-LTE)

<u>High Resolution Data (Unresolved Bands)</u>

- Cross-sections (2-3% accuracy) for 180 – 300 K and 0.001 – 1 bar air at 0.01 cm^{-1} resolution.